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Research progress on the empowerment mechanism and effect of industrial internet

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Abstract: *As an important component of new-type infrastructure, industrial Internet has been paid great attention by policies at all levels because of its enabling characteristics, and has gradually become an important engine for the integration and development of digital economy and real economy, which has aroused widespread concern in academic circles and formed fruitful research results. However, the existing research shows the characteristics of "wide but scattered perspective, many achievements but less focus", which is not conducive to the in-depth study of industrial Internet empowerment issues and the in-depth promotion of related policies and practices. Therefore, this paper systematically sorts out the relevant literatures on the empowerment mechanism and effects of industrial Internet. Firstly, it clarifies the scientific connotation of industrial Internet, its platform and architecture; Secondly, the empowerment mechanism of industrial Internet is refined from the perspectives of micro-enterprise, meso-industrial chain and macro-industrial agglomeration, and on this basis, the empowerment effects of industrial Internet such as enterprise intelligent transformation effect, manufacturing transformation and upgrading effect and industrial transformation effect are summarized. Finally, according to the characteristics of the existing research, especially the shortcomings, some suggestions and prospects for future expandable research are put forward.*

Keywords: *Industrial Internet; Platform connotation; Empowerment mechanism; Empowering effect*

1. Introduction

In recent years, industrial internet, as an important component of new infrastructure, has been highly concerned by national policies. Following the German Industry 4.0 strategy and the American Industrial Internet strategy, China released the national strategy "Made in China 2025" in May 2015, striving to achieve "overtaking in corners" in the new round of scientific and technological revolution and industrial revolution. By analyzing Made in China 2025, it is found that its core path is the deep integration of manufacturing and Internet, which can be described as the prelude to the development of China's industrial Internet. Subsequently, policies related to industrial Internet were introduced one after another. Among them, the landmark policy is the Guiding Opinions on Deepening "Advanced Manufacturing Industry in internet plus" and Developing Industrial Internet issued by the State Council in November 2017. The policy clearly defines the enabling attribute of industrial Internet, and points out that the accelerated development of industrial Internet "is conducive to accelerating the development of intelligent manufacturing, optimizing the allocation of production and service resources in a wider range, more efficiently and more accurately, promoting the transformation and upgrading of traditional industries, giving birth to new technologies, new formats and new models, and providing new kinetic energy for the construction of a manufacturing power". Further deployment of the Tenth Five-Year Plan for Digital Economy should "build a reliable, flexible and safe industrial Internet infrastructure to support ubiquitous connection, flexible supply and efficient allocation of manufacturing resources". Under the reasonable guidance of a series of policies, the construction of industrial Internet has been promoted rapidly, and its empowering effect on the transformation and upgrading of manufacturing industry has also begun to appear. According to the White Paper on Economic Development of China Industrial Internet Industry (2022) issued by China Industrial Internet Research Institute, in 2021, the added value of China's manufacturing industry driven by industrial Internet will reach 1.75 trillion yuan, with a nominal growth rate of 17.78%; It led to 14.2432 million jobs and 1.4291 million new jobs. The Report on Innovation and Development of Industrial Internet

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(2023) shows that China's industrial Internet has moved from the initial exploration stage to the rapid promotion stage, with an industrial scale exceeding 1.2 trillion yuan. Industrial Internet has been fully integrated into the economic categories of 45 countries, covering more than 85% of industrial categories, and nearly 8,000 digital workshops and smart factories have been built. It can be said that the industrial Internet, as an important cornerstone of the fourth industrial revolution, can provide strong kinetic energy support for the transformation and upgrading of traditional industries, the cultivation and expansion of emerging industries and the promotion of deep industrial integration and development. In response to the series of industrial Internet policies and their practice, the research on industrial Internet empowerment has also been carried out layer by layer, and has produced rich research results. Looking at the existing literature, it is found that the research on the theme of industrial internet empowerment is mostly carried out from the aspects of empowerment connotation, empowerment mechanism and empowerment effect, and presents the characteristics of "wide but scattered perspective, more achievements but less focus", which needs to be systematically sorted out to form a relatively complete theoretical system, so as to provide a full-perspective reference for in-depth research on industrial internet empowerment, as well as a more comprehensive reference for supporting policies and industrial practice of industrial internet. In this regard, this paper first combs the connotation of industrial Internet, its platform and architecture, then summarizes the empowerment mechanism of industrial Internet from micro, meso and macro levels, and refines the empowerment effect of industrial Internet accordingly. Finally, based on the existing research status, some research prospects are put forward.

2. The connotation of industrial Internet

Following the deployment of industrial Internet or Industry 4.0 strategy in the United States and Germany, China, Japan, France, Britain and other countries have joined the layout of industrial Internet, and the scientific definition of industrial Internet is the basis for the implementation of this strategy. With regard to the definition of industrial Internet, it is more representative to elaborate on the implementation background of the United States, Germany and China. First, from the perspective of the United States, the concept of industrial Internet was first put forward by the American General Electric Company. According to the company, the industrial Internet is a brand-new industrial format, industrial technology facilities and new technology application mode by constructing four functional systems, deeply integrating the new generation of information technology with traditional industries, and closely connecting equipment, production lines, factories, suppliers, products and customers, and realizing the all-round interconnection of people, machines and things.[1] Since then, five major American industrial enterprises (Cisco, General Electric, Intel, AT&T, IBM) have defined the industrial Internet as an Internet of Things that uses advanced data analysis methods to assist industrial intelligence and improve business output.[2]Second, from the perspective of Germany, the essence of Germany's "Industry 4.0" is still the industrial Internet, which can be summarized as one core, two strategies, three major integrations and eight initiatives, namely "intelligence+networking" as the core; Adopt market strategy and leading supplier strategy; It presents "vertical integration of production and digital integration of engineering and horizontal integration of manufacturing industry"; The eight measures are technology reference system, model management, industrial broadband infrastructure, security mechanism, innovative organization and design, vocational training, improving rules and regulations and improving resource efficiency.[3]Thirdly, from China's perspective, the concept of industrial internet has gone through the process of change from "Made in China 2025" to "Collaborative Manufacturing in internet plus", to "Advanced Manufacturing in internet plus" and then to "Industrial Internet";[4] It is considered that industrial internet is an industrial and application ecology formed by the all-round and deep integration of the Internet and the new generation of information technology and industrial systems, and it is the key comprehensive information infrastructure for the development of industrial intelligence. Its essence is based on the network interconnection among machines, raw materials, control systems, information systems, products and people, and it realizes intelligent control, operation optimization and changes in production organization mode through comprehensive depth perception, real-time transmission and exchange, rapid calculation and processing and advanced modeling and analysis of industrial data. In addition, some scholars have explained the industrial Internet from different perspectives: from the perspective of the relationship between the industrial Internet and the Internet of Things, the industrial Internet is a new format generated by the integration of the Internet of Things and industry;[5] From the application perspective of industrial Internet, relying on the interconnection of "people/machines/things", industrial Internet is the key foundation for opening up industrial elements, industrial chains and value chains, promoting the establishment of a new industrial manufacturing and service system, and realizing a brand-new

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industrial ecology and a new application model.[6]Generally speaking, although the existing literatures have different emphases on the connotation of industrial Internet, they basically focus on internal factors (demand change), kernel (cyber-physical systems), basic framework (network, platform, data, security) and empowerment direction (intelligent manufacturing, integrated development and industrial upgrading), and the analysis has been comprehensive and in-depth.

3. Enabling mechanism of industrial Internet

Empowerment refers to the process in which an individual or organization has the ability to control the objective conditions and environment and replaces the sense of powerlessness. Industrial Internet deeply promotes the high-quality development of manufacturing industry from the three levels of enterprises, industries and regions.[7]Among them, the high-quality development of the empowerment industry is the focus of existing research, including the digital intelligent transformation of the empowerment industry, the platform of the industrial chain, and the virtual agglomeration of the industry. Generally speaking, the existing literature mainly expounds the empowerment mechanism of industrial Internet from the perspectives of micro-enterprise, meso-industrial chain and macro-industrial agglomeration, and has formed a relatively perfect research system.

3.1. Micro-enterprise perspective of industrial Internet empowerment mechanism

At the micro-enterprise level, the industrial Internet mainly empowers the digital transformation of enterprises and the service of their products. On the one hand, the industrial Internet platform empowers enterprises to digitally transform, which means that the industrial Internet platform empowers enterprises with big data capabilities through digital technologies such as big data and cloud computing.[8]By collecting, classifying, analyzing and sharing the data generated by the enterprise management, the enterprise data resource base is built.[9]Specifically, it is divided into two steps. First, the platform realizes data deployment by empowering organizations; Second, organizational empowerment promotes enterprises to create data competitive advantages.[10]Some scholars have also analyzed the promotion of industrial internet platform data empowerment to the digital transformation of enterprises from its platform connectivity, platform intelligence and platform analysis capabilities. Specifically: First, the platform helps to realize the effective connection between people, things and information.[11]And then promote the digital transformation of enterprises through the ubiquitous connection and interaction of data; Second, the platform provides data resources for enterprises through network and data collection, and then provides intelligent support for enterprise design collaboration, management collaboration and supply-demand docking, and promotes the digital transformation of enterprises;[12]Third, the platform analysis ability helps enterprises to expand the breadth and depth of data, realize the intelligent decision-making transformation of enterprises, and thus promote the digital transformation of enterprises. In addition, according to the evaluation of basic support ability, data aggregation ability, new model application evaluation, service innovation ability evaluation and sustainable development ability evaluation, the industrial Internet platform can effectively drive the digital transformation of enterprises through basic support and data aggregation.[13]On the other hand, the industrial Internet empowers enterprises to transform their products into services, which means that the industrial Internet enables enterprises to transform their products into services by giving them the ability of intelligent manufacturing and productization of services.[14]It mainly includes two aspects. First, for related enterprises, enterprises provide professional consulting services through a large number of data processing and analysis, thus producing the knowledge combination of products and building the knowledge combination of "industrial internet". Second, for ordinary users, through the empowerment of the industrial Internet, enterprises can conduct in-depth mining and multi-dimensional analysis of data, promote the accuracy of supply, and solve the personalized needs of the market. Large-scale personalized customization is the inevitable trend of future manufacturing development.[15]For example, Haier COSMO platform accurately grasps the needs of users through big data analysis, and realizes personalized customization by allowing users to participate in the production process.[16]

3.2. Industrial Internet Empowerment Mechanism from the Perspective of Meso-industrial Chain

At the middle level of the industrial chain, the industrial Internet mainly empowers the platform of the industrial chain, including two perspectives: First, from the perspective of the relationship between enterprises, the digitalization of enterprises will connect countless enterprises together to form a

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honeycomb-shaped industrial chain platform. Specifically, the industrial internet can aggregate the data information of various enterprises, reconstruct the connection between enterprises according to different matching rules, and finally transform it into a three-dimensional connection.. On this basis, enterprises can realize the collaboration and docking of data resources such as enterprises, industries, products, markets and R&D.[17]Finally, this relationship between enterprises can make the production factor resources more concentrated, thus promoting the orderly flow and coordinated development of the industry or regional factor resources. Second, from the perspective of the whole industrial chain, the deep sub-optimization of equipment, production, management, after-sales and other scenarios is realized through the whole industrial chain of China Unicom and superimposed data analysis.[18]Specifically, relying on the industrial Internet, the majority of small and medium-sized enterprises can enter the supply chain network with integrated enterprises as the core, share information such as customer demand, product design, process documents, supply chain planning, inventory, etc. with integrated enterprises and upstream and downstream manufacturers, and then participate in the process of product R&D, design and collaborative manufacturing. Through the collaborative and synchronous production of the supply chain, the precise docking of parts supply can be achieved on time, in quality and quantity, and the close cooperation with large enterprises can be achieved.[19]Finally, with the help of the composite structure, the industrial chain can be more stereoscopic, the ability to resist risks is stronger and the production performance of enterprises is higher.[20]In a word, the platformization of industrial chain makes the relationship between enterprises closer and can realize the optimal allocation of resources in all aspects.

3.3. Industrial Internet empowerment mechanism from the perspective of macro-industrial agglomeration

At the macro industrial agglomeration level, industrial internet mainly empowers the continuous improvement of industrial virtual agglomeration level. Industrial Internet empowers virtual industrial agglomeration, which mainly shows that industrial Internet connects machines, people and data around the world, combines data collection and analysis with operation prediction at a deeper level, allocates resources and sells products around the world, reduces redundancy, and realizes global manufacturing networking.[21]On the one hand, industrial internet can efficiently connect and integrate the key points of industrial virtual agglomeration in different periods: in the initial stage of industrial virtual agglomeration, the dimension of connection is mainly products, and industrial internet is mainly reflected in the interconnection and mutual promotion of production and business activities (including R&D, manufacturing, marketing, after-sales service and procurement); In the middle stage of industrial virtual agglomeration, the dimension of connection is mainly related to the industrial chain. Industrial Internet aims to efficiently gather and share the stakeholders (including suppliers, customers, government departments, high-efficiency scientific research institutes and competitive enterprises) and their corresponding resources in all aspects of the industrial chain, thus realizing the transformation of business model. In the later stage of industrial virtual agglomeration, the dimension of connection is mainly industrial system, and industrial internet can provide platform support for industrial integration and cross-industry integration (including related industries, unrelated industries and Internet industries).[22]On the other hand, the industrialization development process of industrial Internet itself is a process of continuous virtual agglomeration of related industries, which is mainly realized based on the industrialization of a new generation of information technology. Generally speaking, the industrial agglomeration brought by the development of Internet and Internet of Things mainly includes three aspects: one is geographical agglomeration, the other is pure virtual agglomeration, and the third is that geographical agglomeration and virtual agglomeration are carried out at the same time.[23] Generally speaking, there are few literatures about industrial Internet-enabled industrial agglomeration, and the existing studies are mainly embodied in two aspects: enabling related industrial agglomeration and industrial agglomeration in different periods.

4. The enabling effect of industrial Internet

To a great extent, the empowerment effect of industrial Internet is the practical transformation of empowerment mechanism. In specific research, the industrial Internet empowerment mechanism often corresponds to theoretical analysis, while the industrial Internet empowerment effect mostly corresponds to empirical research. In most cases, scholars who pay attention to the mechanism of industrial Internet empowerment will also attach importance to the analysis of the empowerment effect of industrial Internet. Corresponding to the empowerment mechanism of industrial Internet, the

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empowerment effect of industrial Internet is mainly manifested in three aspects: enterprise intelligent transformation from a micro perspective, manufacturing transformation and upgrading from a medium perspective, and industrial transformation from a macro perspective.

4.1. Industrial Internet Enterprise Intelligent Transformation Effect

The enterprise intelligent transformation effect of industrial internet refers to the use of internet plus to optimize the efficiency of manufacturing links such as design, production, management and service based on the new generation of information technology, so as to realize enterprise intelligent decision-making.[24]Many studies have shown that industrial internet can realize enterprise intelligent manufacturing by empowering enterprises to digitize production and platformize industrial chain. At present, the indicators to measure the intelligent transformation of enterprises promoted by industrial Internet mainly include three aspects: intelligent products, intelligent production and intelligent services. Specifically, first of all, from the perspective of innovation of working principle and mechanical products, industrial Internet is helpful for enterprises to produce intelligent products.[25]For example, the emergence of 3D printing and the shale gas revolution increased the proportion of shale gas production in the United States to 37% in 2012 from 12% in 2007. In addition, some scholars have analyzed from the perspective of user interaction and participation, and found that the industrial Internet has promoted the emergence of user-centered intelligent products. For example, the intelligent product Xin Kitchen Refrigerator of Haier COSMO platform has realized the intelligent transformation of users' participation and interaction while enhancing the unit value. Secondly, from the perspective of product design, manufacturing and management level, industrial internet is helpful for intelligent production of enterprises.[24]For example, the new digital design of aircraft shortens the R&D cycle by 40% and reduces the amount of rework by 50%; the intelligent manufacturing has achieved the goal of "reducing staff, increasing efficiency, improving quality and ensuring safety"; and the intelligent management of Boeing has reduced the R&D cost by 50%. Thirdly, from the perspective of customized production scale, industrial internet is helpful for enterprise intelligent services. For example, Red Collar Group's suit customization makes the average annual sales revenue and profit increase by more than 150%. Finally, from the point of view of personalized customization, Haier COSMO is helpful to the intelligent production of enterprises, reducing the rejection rate and inventory rate while improving the production capacity. In addition, some scholars have found that there is a positive correlation between the level of industrial internet and the level of enterprise intelligence through the study of the number and proportion of enterprises building e-commerce trading activities, the number of websites owned by enterprises, e-commerce sales and other indicators.[26]However, due to the constraints of various factors in the process of enterprise transformation, the intelligent transformation of enterprises faces a lot of pressure. Among them, it is more obvious that the industrial internet restricts the intelligent transformation of enterprises because of the inconsistency of technical standards, the lack of innovative talents and funds, and the low degree of industrial integration of industrial Internet platforms.

4.2. Industrial Internet manufacturing transformation and upgrading effect

The transformation and upgrading effect of industrial internet in manufacturing industry means that the application of industrial internet contributes to the deep integration of new information technology and manufacturing industry, and promotes the transformation and upgrading of manufacturing industry by changing its value chain, industrial chain and industrial model[26]. Generally speaking, this effect can be divided into direct effect and indirect effect. From the direct effect, the existing literature mainly measures from two angles: the upgrading of manufacturing structure and the improvement of production efficiency. Among them, the upgrading of manufacturing structure includes two dimensions: rationalization and upgrading of manufacturing industry, and production efficiency is mainly measured by manufacturing efficiency. The results show that: firstly, the influence coefficient of the development level of industrial Internet platform on the rationalization of manufacturing industry is 2.428, which indicates that the development of industrial Internet platform can effectively promote the improvement of the internal structure coordination of manufacturing industry and the quality of aggregation, thus promoting the rationalization of manufacturing industry; Secondly, the influence coefficient of the development level of industrial internet platform on the advanced manufacturing industry is 0.04, which indicates that the development of industrial internet platform can effectively promote the evolution and upgrading of low-tech manufacturing industry to high-tech manufacturing industry, and then promote the advanced manufacturing industry; Thirdly, the influence coefficient of the development level of industrial Internet platform on manufacturing efficiency is 0.047, which indicates

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that industrial Internet can effectively promote the improvement of manufacturing efficiency, and then promote manufacturing efficiency.[26]In addition, some scholars have found that, under the premise that other conditions remain unchanged, for every one unit increase in the development level of industrial Internet, the upgrading of manufacturing industry will directly increase by 0.0483 units.[27]From the indirect effect, it is found that every increase in the development level of industrial Internet will also increase the innovation level by 1.2367 units, which will lead to an indirect increase of 0.1550 units (0.1253×1.2367=0.1550) in the upgrading of manufacturing industry, and the indirect effect accounts for 66.55% of the total effect.[27]In addition, the effect of industrial Internet in promoting the transformation and upgrading of manufacturing industry is also reflected in the shift of manufacturing design from physical space to virtual digital space, the shift of manufacturing production mode to personalized customization, and the shift of manufacturing value from tangible products to providing complete solutions.

4.3. Industrial Internet Industrial Transformation Effect

The industrial transformation effect of industrial Internet means that industrial Internet has promoted the application of digital, networked and intelligent technologies, which has changed the industrial form and thus promoted industrial transformation.[24]This industrial transformation effect is mainly manifested in two aspects: first, it can generate many emerging industries; Second, it can promote the integration and innovation of informatization and traditional industries.[22]Specifically, on the one hand, the industrial Internet has promoted the birth of many emerging industries. From a technical point of view, the industrial Internet has promoted the birth of 3D printing, 3D printing, augmented and virtual reality, collaborative robots, interconnected machine vision, unmanned aerial vehicles and driverless car industries.[24]From the perspective of enterprise-related, industrial Internet has spawned many related enterprises. For example, Shaanxi Industrial Cloud provides artificial intelligence services for related enterprises in terms of enterprise innovation and development, economic transformation, and integration of the two industries. On the other hand, the industrial Internet promotes the integration and innovation of informatization and traditional industries. From an economic point of view, the industrial Internet involves a wider range of industries than the traditional economic categories. From the perspective of energy consumption, the integration of intelligent technology and sound network can save energy and reduce consumption and cost; From the perspective of physical assets, industrial internet can promote the technological integration between new equipment and old equipment, improve the total factor survival rate and reduce the cost structure. Generally speaking, this kind of inquiry is limited at present, and the research mostly stays at the theoretical level.

5. Literature Review and Research Prospect

By combing and analyzing the existing literature, it is found that the research on the theme of industrial internet empowerment mainly focuses on the connotation and structure of industrial internet, the empowerment mechanism of industrial internet, the empowerment effect of industrial internet and so on. Although fruitful research results have been achieved, there are still obvious shortcomings, mainly in the following aspects:

First, the research on the connotation of industrial Internet has not yet reached a consensus. Although most scholars basically rely on the relevant policy documents of the United States, Germany and China to define the connotation of industrial Internet, different scholars often have their own emphasis when quoting the policy documents of various countries, and the industrial Internet policies of the United States, Germany and China are inherently quite different, resulting in great differences in the definition of industrial Internet in different documents. Even the documents supported by China's industrial Internet policy documents have different definitions of industrial Internet due to their different focus.

Second, the research on the empowerment mechanism of industrial Internet is still scattered. Although the existing literature has made fruitful discussions on the empowerment mechanism of industrial Internet from different perspectives, such as micro, meso and macro, these discussions are still scattered, lacking a relatively unified analytical framework and combing the logical relationship among micro, meso and macro empowerment mechanisms.

Third, the research on the empowerment effect of industrial internet is still not in-depth. In the research on the empowerment effect of industrial Internet, most literatures use theoretical deduction, case analysis, macro-econometric demonstration and other methods to study, while few literatures use

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mathematical model derivation, multi-case analysis, micro-econometric demonstration and other methods to analyze, which makes its research not comprehensive and in-depth. When measuring the empirical evidence, due to the data constraints, most documents only adopt relatively simple industrial Internet evaluation indicators.

Based on the above analysis, this paper believes that the research on the theme of industrial Internet empowerment needs to be broken through in the following aspects:

The first is to improve the research on the scientific connotation of industrial Internet. Although the concept of industrial internet originated from the United States, the policy and practice of industrial internet in China are basically synchronized with those in the United States and Germany. Different from many other new-generation information technologies, industrial Internet has a fertile growth soil in China. Therefore, the research on the scientific connotation of industrial Internet should be based on the national conditions of our country, with the fundamental purpose of serving the industrial Internet policy, especially solving the practical problems of industrial Internet, focusing on the development foundation, platform support, basic architecture and core functions of industrial Internet.

The second is to strengthen the research on the empowerment mechanism of industrial Internet. As an important component of new infrastructure, the industrial Internet is not only named "work", that is, the industrial Internet is not only empowering industry. Therefore, the research on the empowerment mechanism of industrial Internet should first break through the scope limitation of industrial field, and should be extended not only to other industrial fields such as agriculture and service industry, but also to wider fields such as social governance and ecological environment. Secondly, it is urgent to build a unified analytical framework compatible with micro, meso and macro levels in the study of industrial Internet empowerment mechanism, and this framework should be as concise and clear as possible. Finally, the research on the empowerment mechanism of industrial Internet should be based on a unified analysis framework to sort out the logical relationships among the action paths, such as the relationship between digitalization and platformization of industrial chain, and whether platformization of industrial chain will indirectly promote industrial agglomeration.

The third is to break through the research on the empowerment effect of industrial Internet. The research on the empowerment effect of industrial internet should achieve breakthroughs in three aspects: first, the breakthrough of index measurement, which is a complex thing in itself, and its index measurement should be based on the scientific connotation of industrial internet, and try to construct refined composite indicators from micro, meso and macro perspectives for analysis; Secondly, the breakthrough of empirical data. Although the existing statistical data of industrial Internet are limited, in recent years, the practice of industrial Internet has produced a large number of microscopic data, so we should try our best to use data mining technology to transform these practical data into research data. Finally, it is a breakthrough in research methods. We should comprehensively and deeply analyze the empowerment effect of industrial internet by applying theoretical deduction, mathematical model derivation, multi-case joint analysis and personalized econometric empirical model.

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